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1. The first step in the process is to identify the problem or issue that needs to be addressed. This involves gathering information and understanding the context of the problem.

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Final Report for AFOSR Project on "Estimating Spatial Location"

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The overall purpose of the research done under the Air Force Grant was to test a model of bias in the judgment of spatial location. The model holds that the representation of locations is not itself biased, but that it is the process of estimation that leads to bias. The process we argue is one of combining category and fine grain information about location (e.g., for any item in a circle, polar coordinates as specific locations and quadrant as category location). In the early years of the grant we made an initial test of the model in a set of four experiments that appeared in *Psychological Review* (Huttenlocher, Hedges, and Duncan, 1991. Categories and particulars: Prototype effects in estimating spatial location. *Psychological Review*, 98, 352-376).

In the later years we have carried out a set of experiments to test the model much more extensively. The work has not been submitted for publication, but is in preparation. A summary of the studies follows:

1. Category Restructuring Experiments

Purpose

This set of experiments was designed to test whether bias occurs at the time of encoding or at the time of retrieval (i.e., is a bias in representation) (i.e., is a bias in estimation as predicted by our model). The model holds that information about particular location combined with information about category membership when the location is encoded into memory, or when the information is retrieved from memory? To answer this question, we conducted several experiments which manipulated the categorical structures of a space as well as the time at which categorical structures were introduced (at the time of encoding, or at the time of retrieval). The first experiments examined whether or not a geometric space would be subdivided in different ways under different instruction conditions. Then we conducted experiments which attempted to alter the structure imposed upon a space at the time of retrieval. We theorized that if spaces can be subdivided in different manners under different conditions, and structure changes at the time of responding resulted in alternative subdivision, then prototype information is combined with particular information at the time of retrieval from memory. If, on the other hand, subdivision of space is not affected by structural changes at the time of responding, information about true location is likely combined with category information when it is encoded into memory.

Subjects

100 subjects participated in this study. Subjects were University of Chicago students and were paid for their participation.

Methods and Procedures

The initial experiments were designed to determine whether or not a space with a natural form of organization could be organized differently if a functional significance was attached to the new form of organization. These experiments utilized a space with a known natural categorical organization. Subjects were shown a long narrow rectangle (which is normally divided at the center into two categories) with a line dividing it into two unequal regions. Subjects were told that the box represented a divided pet shop cage. In the larger of the two sections resided guinea pigs, while hamsters lived in the smaller section. Subjects were told that the barrier between the sections was immovable and that animals could not cross it by any means. After testing to ascertain subjects were familiar with the cage layout, subjects were shown single points within the rectangular space. They were instructed to name which animal the point represented and then were required to reproduce the location of the point from memory.

Another branch of experiments involved the use of an irregular space portrayed as a fictional country. Points were shown within this space in various distributions. One condition used a uniform distribution of points, other had distributions clustered around locations defined for the subjects as major cities. Subjects in all conditions were required to reproduce the locations from memory. In the baseline conditions, subjects were given instructions about reproducing the location of villages within the fictional country. They saw and reproduced one point at a time. In the structure change conditions, subjects were told that there were two identically shaped fictional countries and that each had major cities in different locations. Subjects were trained on both of the major city conditions from the baseline experiments. During testing, subjects were shown a single point within the country. Before reproducing that point they were told that the stimulus display had been one of the two countries. Subjects then reproduced the location of the point from memory.

Results

For all experiments, true stimulus locations were subtracted from the subjects' response values. Mean directed error were computed for each stimulus location and were plotted against true location.

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In the experiments involving the rectangular space, it was found that, while subjects could easily use the new categorical structures for the purpose of identifying individuals based on location, those categorical structures were not adopted in their reports of location. Bias in reporting matched those from earlier work involving the simple reproduction of points within a rectangular frame (no additional instructions or training). The bias plots from these experiments indicated the use of two equal categories with central prototype values. Responses were pushed outward from the center and in from the ends.

In the fictional country experiments, the uniform distribution condition was used as baseline data to establish what might be the normal spontaneous organization of the space. The clustered distributions indicated that reports of location are affected by proximity to "major city" landmarks.

Data has been collected under conditions where alternate forms of organization were presented at encoding and retrieval. Data is still under analysis.

2. Asymmetry Dot Experiment

Purpose

The purpose of this study was to test predictions made by the model for cases where inter-point distances need to be estimated. We theorized that the combination of particular information with prototype information could yield the types of over and under estimation found by other researchers under different conditions. It was expected that prototype weighting would differentially effect the estimated distance between points depending upon where the pair of points was located with respect to the prototype and category boundaries.

Subjects

60 University of Chicago students participated in this study. There were roughly equal numbers of males and females. Subjects were paid for their participation.

Methods & Procedures

Stimuli consisted of pairs of 1.5 mm dots located within a 15 cm circle. The stimulus set consisted of 72 critical comparison pairs and 48 filler pairs which were included to eliminate subject expectations about dot pair types. Critical comparison pairs were selected from two groups; pairs whose angular values represented the prototype of the category and a non-prototype location, and pairs whose angular values were

symmetrical about the category prototype. For critical comparison pairs, radial values were held constant within a given pair. Filler pairs consisted of dots of varying angular value and radial value. On a given trial, subjects were presented with a circle in which each of the dots from a pair were shown sequentially. Subjects were then given a response circle in which one of the stimulus dots was presented in its correct location. Subjects were instructed to reproduce the location of the missing dot. Each pair was displayed twice, one trial in which each of the two dots was fixed for the subject. The order of presentation of stimulus dots was counterbalanced within and between subjects.

Results

Subjects responses were coded by an naive observer. 15% of the data were scored by a second experimenter. Inter-scorer reliability was .99. Only responses for critical comparison pair trials were analyzed. Angular distances between the subject response dot and the given dot we computed. Mean intra-point distances were computed for each pair type (across prototype, prototype fixed, prototype estimated). These distances were compared to the true intra-point distances of the stimuli.

For pairs in which the stimulus consisted of a dot on the prototype and a non-prototype dot, and where the prototype dot was the dot fixed in the response circle, intra-point angular distances were consistently underestimated.

For pairs in which the stimulus consisted of a dot on the prototype and a non-prototype dot, and where the non-prototype dot was fixed in the response circle, intra-point distances were consistently overestimated.

For pairs in which the stimulus consisted of two dots symmetrically oriented around the prototype, intra-point angular distances were accurately represented, regardless of which dot had been fixed.

3. Line in Frame Experiments

Rationale

The purpose of these experiments was to choose between two explanations for bias in reproducing a line within a frame. We used an interference task between the presentation of the angle within a frame and response in order to decrease the certainty of the subjects' memory for the orientation of the line. According to Schiano and Tversky, an interference task should not affect the extant of the bias since bias is attributed to perceptual. However, we believed that the extant of bias would be increased since using categories results in greater bias when memory is more uncertain. The interference task

consisted of the presentation and immediate response to an angle within a frame. The degree of bias for the interference angle was compared to the first angle presented.

Schiano and Tversky (1992) had subjects reproduce the angle of a line presented in an "ell" shaped frame. They found that subjects tended to misplace the angle of the line away from the edges of the frame and away from the 45 degree line. Schiano and Tversky originally attributed this pattern of bias to perceptual factors involved in extracting the frame's major axes of symmetry. According to this major axes hypothesis, lines should *appear* tilted away from present axes of symmetry such as the edges of the frame and implied axes of symmetry such as the diagonal. Furthermore, the degree of apparent tilt should be greater for lines near present axes of symmetry than for lines near implied axes of symmetry. We, on the other hand, believed this bias was predominantly caused by the categorization of the frame into equal halves. We added several conditions where the frame was tilted so that the frame opened upwards centered about the vertical axis and 22.5 degrees to either side of vertical. If the explanation of the bias given by Schiano and Tversky was correct, the pattern of bias should have been relatively unaffected by the orientation of the frame. In particular, the degree of bias for lines near the present axes of symmetry should have been greater than for lines near implied axes of symmetry. If our explanation is correct, the degree of bias due to categorization should be affected by the frame's tilt. We believe category effects are greater when subjects are less certain of the orientation of the line. Therefore, we predicted that in some cases the degree of bias for a line near an implied axis of symmetry should have been greater than for lines near a present axis of symmetry. In general, we found that subjects' reproductions of lines confirmed our predictions. The degree of bias appeared to be related to the certainty of their memory for line orientation.

Methods

Unlike earlier experiments, a computer program was written to precisely control presentation of the lines within the frame and the delays before the responses. Booklets were created containing only response pages separated by blank colored sheets of paper. First, the subjects were presented with an angle within a vertically oriented frame on the computer screen. Next, the subjects were presented with an interference angle. Then, on a signal from the computer program, the subjects turned to the next response page and reproduced the interference angle in their booklet. Finally, the program instructed subjects to turn to the next response page and reproduce the original angle. As in the previous experiments, the frame lines were 10 cm long and 1.75 mm wide and the stimuli line was 9 cm long and 1 mm wide. There were 17 stimulus lines at 5 degree increments

from 5 to 85 degrees. 40 undergraduates, predominantly freshman and sophomores, at the University of Chicago were tested.

Results

The subjects categorized the original and the interference angles within the vertically oriented frame into equal halves, just as the subjects had in the previous experiments. The subjects skewed their placement of the line towards a central angle in the half of the frame in which the line appeared. As predicted, the extant of bias was greater for the original angles than for the interference angles. This difference was found to be significantly different by fitting a regression line to the bias slopes for each half of the frame. The regression slopes were significantly more negative for the original angle than for the interference angles.

The difference in the extant of the bias for the original and interference lines appears to be related to the standard deviation of the subjects' responses. For the interference angles, the standard deviation of responses and the extant of the bias was smaller. For the original angles, the standard deviation and the extant of the bias was larger.

4. Muller-Lyer Illusion Experiment

Rationale

The purpose of this study is to test whether certain biases are, as we expect, due to misrepresentation in memory. The results of our study of the effect of interference on bias in reproducing a line in a frame suggested that bias that had been attributed to perceptual processes was due instead to category effects. We found that interpolating an interference task between display and response resulted in increased bias in responding. We decided to study another bias in reproduction that we thought was due to perceptual factors -- the Muller-Lyer Illusion. Comparing the size of errors between "normal responding" and responding after interference may be a good general method for distinguishing biases due to perceptual factors and biases to categorization or other conceptual factors. We believed that the size of the errors in reproducing the vertical line segment in a Muller-Lyer display would be unaffected by the use of an interference task. However, we expected the standard deviation of responses to be increased since memory for the length of the vertical line would be less certain.

Methods

The subjects were presented with a vertical line segment on the computer. The subjects saw one of the following displays: a vertical line segment with arrows attached to the ends of the vertical line that pointed inwards, a vertical line segment with arrows that pointed outwards, or simply a vertical line. Ten different lengths of lines were presented. The length of the arrow segments was proportional to the length of the vertical line. The subjects saw each of the three types of lines at all 10 lengths for a total of 30 trials. The order of the trials was completely random. After the display disappeared the subjects reproduced the length of the line using the computer. They pressed the "l" key to lengthen a line and the "s" key to shorten a line that appeared on the computer monitor. When they were satisfied with their estimate of the line length, they hit the space bar and next trial was presented.

For the interference condition, the above procedure was the same except that the subjects had a task interpolated between the line display and the reproduction of the length of the vertical line segment. The subjects were presented with a 3 x 3 grid of shaded and light squares. Five of the squares were shaded and four of the squares were light. The coloration of the squares was randomly determined. After the display disappeared, another grid was presented with an "X" in one of the squares. The square with the "X" in it was also randomly determined. The subjects' task was to determine if the square with the "X" was previously shaded or light. If they thought it was shaded, they hit the "s" key, if they thought it was light they hit "l" key.

Results

The errors in reproduction suggest that both conceptual and perceptual factors influenced responses. Consider results of the non-interference condition first. There was a general tendency to overestimate the length of short lines and underestimate the length of long lines. We believe this is a category effect which we have seen in the estimation of simple line segments without arrows. Our interpretation is that subjects are forming a category of line length and biasing their responses towards the average length of line presented. There was also an effect of the type of line presented which we attribute to perceptual factors. At each of the ten lengths, the average error when the arrows pointed inwards is greater than the error for the vertical line alone which is in turn greater than the error when the arrows point outwards. This difference in errors for the three types of lines is consistent with previous research on the Muller-Lyer Illusion. The degree of difference between the three types of lines increases slightly as the length of the vertical line increases.

The results of the interference condition are similar but more difficult to interpret. As in the non-interference condition, subjects seemed to form a category of the line lengths biasing their reproductions towards an average length. The degree of shrinkage is slightly greater in the interference condition than in the non-interference condition. This prediction is consistent with our general finding that category effects increase when memory is less certain. There is also an effect of the type of line on errors in reproduction. As in the non-interference condition, errors for lines with inward arrows are greater than errors for the vertical lines alone which are greater than the errors for the lines with outward arrows. However, this pattern is less consistent perhaps because the standard deviation of responses is much higher. For example, the pattern of errors is so variable that it is difficult to determine if the differences between the three types increase with the length of the line. It is also difficult to determine if the difference between the three types of errors in the interference condition is the same as the difference in the non-interference condition. The errors do not appear to be significantly different which is consistent with our prediction. If anything, the difference in errors between the three types of errors seems smaller in the interference condition than in the non-interference condition.

In additional experiments, we are running each type of line in separate experiments in both interference and non-interference conditions. This will enable us to be more certain of what the category of line lengths is based on. Furthermore, the variability in the responses for the interference conditions may be reduced since subjects will be focusing on only one type of line.

5. Same/Different Judgment Experiment

Rationale

The purpose of this study was to determine whether biases in discrimination could be explained using our model. Many experimenters have used same/different tasks which assess the likelihood that similar stimuli will be mistaken for each other. In these tasks, two stimuli are presented and the subject is asked to determine if the stimuli are the same or different. There is a systematic tendency to confuse some pairs of stimuli more often than other pairs even when the pairs have the same actual similarity. We believe that category effects are the source of both the systematic confusions in same/different data and the reproduction errors we have found in free response data. For example, pairs of stimuli that cross category boundaries are less likely to be judged the same than are pairs of stimuli within a category. In reproduction tasks, there is a similar effect of category

use -- stimuli on either side of a category boundary are reproduced as being further away from the boundary. We decided to use the same set of stimuli for a same/different task where the subject is presented with similar stimuli and asked to determine if the stimuli are the same and different and a reproduction task where the subject is asked to reproduce the location of a stimulus. If the systematic confusions of stimulus pairs and the reproduction errors are related to category effects, the data from the same/different task and the reproduction task should reveal the same category structure.

Methods

Same/different data and reproduction data were collected where the responses involved the location of a dot within a vertical rectangle and the angle of a line within a vertically oriented frame.

Vertical Rectangle. For the same/different study, a dot at one of 39 vertical locations was presented for a second within a vertical rectangle on a large computer monitor. After the display disappeared, a second dot was presented within a rectangle on an adjacent large computer monitor. For half of the trials, the second dot was in the same location as the first dot. On the other half of the trials, the second dot was either 30 pixels above or below the first dot. The subjects' task was to determine if the dots were in the same or different locations within the rectangle. If the subjects believed the dots were in the same location, they pressed one key on the computer's keypad, if the subjects believed the dots were in a different location, they pressed another key on the keypad. The keys for responding same and different were counterbalanced between subjects and the hand the subject used to responses was varied within subjects. For the reproduction study, the display of the dot was the same as the first dot in the same/different condition but the subject responded using paper and pencil. After the dot disappeared, the subject reproduced the location of the dot within a vertical rectangle on a response booklet.

Line in Frame. For the same/different study, the methodology for the line in the frame was the same as the vertical rectangle. The frame was oriented vertically and the same distribution of angles was presented as in the previous line in frame studies (5, 10, 15, ...85 degrees). The second angle that was presented on the adjacent monitor was at either the same angle or an angle 5 degrees greater or smaller than the first angle. We compared the same/different data to the results of the previous reproduction study with the vertically oriented frame.

Results

Vertical Rectangle. The subjects same/different errors suggest the vertical rectangle was divided into two categories corresponding to the upper and lower halves. For example, if a dot was presented in the upper half of the rectangle, the subjects were more likely to be confuse it with a second dot that was in the direction of the central value in that half than with a second dot that was closer towards the top or middle of the rectangle. Same responses tended to be most accurate near the center of the two categories. Different responses were most accurate when the dots were in different categories. The reproduction errors also suggested that the subjects categorized the frame into an upper and lower half. Subjects tended to misplace the dots towards the center of the half of the rectangle where the dot was presented. The locations that had the smallest average errors were the same as the locations where the accuracy of same judgments was high -- the center of the two categories. The locations that had the largest errors were the same as the locations where the accuracy of different judgments was high -- near the edge of the category boundary.

Line in Frame. The results of the same/different study for the line within the vertically oriented frame also revealed similar category effects. The subjects appeared to divide the frame into two categories. For example, in the same different study, the subjects were more likely to confuse the first angle with a second angle that was closer to the center of the category than with an angle that was closer to the category boundary or the edge of the frame. Note that this is the same category division that was found in the previous reproduction studies of the line within the frame where angles were misplaced towards the center of the two halves of the frame. Furthermore, there is the same relation between the accuracy of same/different judgments and reproduction errors -- same responses were most accurate for angular locations near the center of the categories where little bias in reproduction was found and different judgments were most accurate when the angular locations were near category boundaries where reproduction responses were most biased.

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